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Effects of Pinyon-Juniper Removal on Natural Resource Products and Uses in Arizona

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Abstract

Results from six treated and control watersheds, along with other results from the southwestern pinyon-juniper type, suggest that: (1) mechanical methods of pinyon-juniper removal are not likely to increase water yield; (2) removal of pinyon-juniper overstory by herbicides can increase water yield; (3) there has been no statistical verification of changes in flood peaks or water quality due to treatment; (4) herbage yields increase after virtually all pinyon-juniper treatments, but potential livestock carrying capacity varies greatly due to differences in plant composition; (5) the response by deer to these treatments is, on the average, neutral; (6) the more successful conversion projects just about break even from a benefit-cost standpoint under 1972 economic conditions.

Keywords: *Pinus edulis*, *Juniperus* spp., watersheds.

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b[Pinus edulis-Juniperus]b

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**Effects of Pinyon-Juniper Removal on Natural
Resource Products and Uses in Arizona**

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Water shortages and threats of water shortages in central Arizona during the mid-1950's stimulated interest in watershed management. It was suggested that much of Arizona's nonagricultural land in the Salt and Verde watersheds should be managed primarily to improve overland water yields, while other uses would have a secondary consideration. Different forms of vegetation manipulation were recommended to achieve water yield increases (Barr 1956). These recommendations had particular significance because a large percentage of the State is in some type of Federal ownership or trusteeship. For instance, in the Salt and Verde watersheds, 55 percent of the pinyon-juniper² vegetation type is managed by the USDA-FS [U.S. Department of Agriculture, Forest Service] and 37 percent is within Indian reservations.

Since managers of Federal lands are committed to the multiple-use concept, any management policy which strongly affects the land must undergo serious examination before being implemented. Watershed studies were quickly set up by Federal agencies to study the impact of vegetation manipulation on watershed management (Kennedy 1959, Le Crone 1959, Reynolds 1959).

²Common and botanical names of plants are listed at the end of this report.

The intent of this Paper is to examine current results of water yield improvement tests in north-central Arizona in light of their impacts on multiple uses of the land. This examination includes water quantity and quality, overstory vegetation, understory vegetation, potential livestock carrying capacity, wildlife values, and recreation and esthetics. The changes in these values are considered in relation to management costs. Emphasis is placed on studies within the Beaver Creek watershed, Coconino National Forest, because considerable multiple use information has been developed there. Results from related studies are utilized as they apply.

The Beaver Creek Project was established in the late 1950's as part of the Arizona Watershed Program. The general objective of the Project was to evaluate land management measures designed to increase water yields. While water yield was to be given major consideration, changes in forage and timber production, wildlife populations, recreational value, and erosion and sediment movement were also to receive attention. Costs and benefits of the various treatments were to be studied so that all aspects of the Project could be evaluated (Brown 1971).

The Beaver Creek watershed is located along the Mogollon Rim on the Coconino National Forest. In 1957, six pilot watersheds were established in the pinyon-juniper type: three in the

Utah juniper subtype ranging from 126 to 362 acres, and three in the alligator juniper subtype ranging from 66 to 346 acres (fig. 1). On areas surrounding these pilot watersheds, juniper was removed on several thousand acres as part of an action watershed-improvement program (H. Brown et al. 1974).

The treatments are being evaluated primarily by the USDA-FS with cooperation of Agriculture Research Service, Arizona Game and Fish Department, Arizona Land Department, Arizona Water Commission, Arizona Water Resources Committee, Colorado State University, Museum of Northern Arizona, Northern Arizona University, University of Arizona, and

USDI Geological Survey. Additional background information can be found in H. Brown et al. (1974).

Research Background

Hydrology

Early estimates of potential water yield increases to be obtained by removal of pinyon-juniper overstory were 0.75 inch from bottom lands to 0.40 inch for slopes (Barr 1956). Later reports were less optimistic. Dortignac (1960) studied runoff efficiencies and infiltration

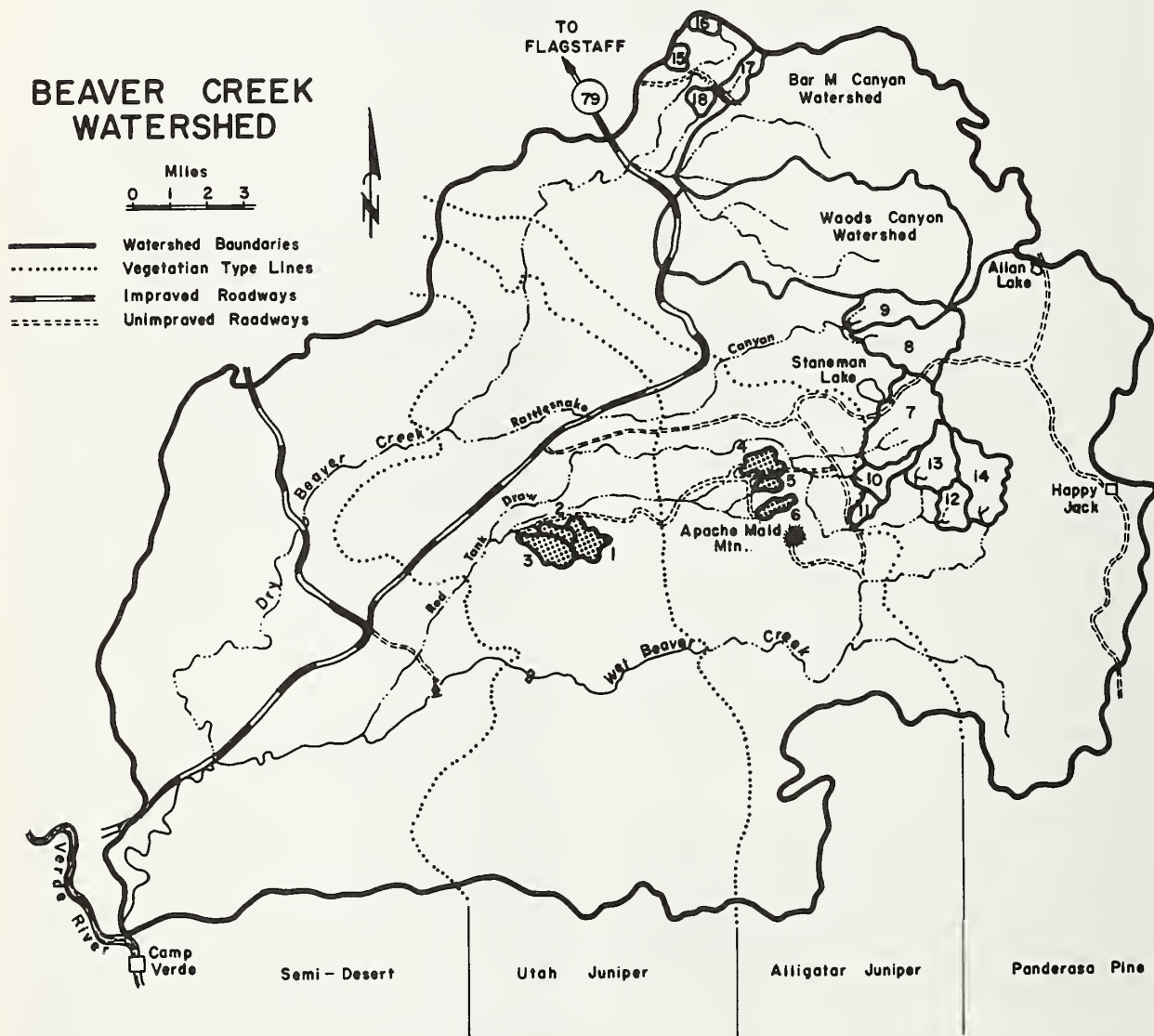


Figure 1.—The Beaver Creek watershed.

rates on pinyon-juniper watersheds, and reported that the possibilities for increasing overland flow were not promising. Skau (1964b) reported that although clearing of Utah juniper may increase the moisture available for forage production, it may have little effect on runoff. During his 2-year study there was little difference in soil moisture between cleared and natural areas, particularly during the winter when the majority of runoff occurs. All plots had unused soil moisture storage capacity.

If the small differential in soil moisture between cabled and natural areas were to be converted into overland flow, nearly one-half would be trapped by the pits created by cabling juniper trees. These pits were estimated to reduce annual flow by 0.09 to 0.27 inch (Skau 1961).

Gifford (1973) reported that only when the debris left from chaining was windrowed did runoff increase in southern Utah. This effect of windrowing was attributed to a combination of decreased infiltration rates caused by severe mechanical soil disturbance, and the retention storage effect which occurs when debris is present. Other work on various components of the hydrologic cycle has not provided strong evidence for or against the improvement of water yields by removal of pinyon-juniper stands (Collings 1966, Gifford and others 1970, Gifford and Tew 1969, Skau 1964a).

One of the earlier watershed tests of the effect of pinyon-juniper control was conducted on an area of sedimentary soils in eastern Arizona. Although pinyon-juniper vegetation was removed from 25 percent of the area by chaining, and brush and duff under ponderosa pine stands were removed by prescribed burning on 13 percent of the area, water yield did not change detectably (Collings and Myrick 1966).

Myrick (1971) attempted a different method of evaluating water yield response to pinyon-juniper removal. He used a "parameter model" to estimate water yields without treatment, and these estimates were compared with observed posttreatment water yields. Water yields were estimated to have increased for 2 years following treatment, then dropped below the expected untreated yields the third and fourth posttreatment years.

Considering all of the documented hydrologic results from the southwestern pinyon-juniper type, the possibility of increasing water yield through removal of the tree overstory does not appear very promising.

Erosion

It has been suggested that pinyon-juniper

stands increase the rates of erosion and sediment movement by suppressing herbaceous understory vegetation (Arnold and Schroeder 1955). Dortignac (1956) found erosion in the Rio Grande Basin was closely related to the condition of the plant cover. Some studies in southern Utah, however, demonstrated no consistent decrease or increase in sediment yields following clearing of pinyon-juniper and seeding to grass (Gifford and others 1970). Other studies showed that both runoff and sediment yields could increase if the slash debris is windrowed following chaining (Gifford 1973).

Range

On the Fort Apache Indian Reservation, herbage yields were strongly depressed as the density of the pinyon-juniper stand increased. It was estimated 10 years would be required after tree removal for a site to reach maximum herbage yields when protected or winter grazed only. At the end of the 10-year period, grazing capacity should have increased threefold (Arnold and Schroeder 1955). Other speculations were that the average animal unit carrying capacity per section (640 acres) would increase from 7.1 to 22.8 in 10 years after pinyon-juniper control. Areas supporting very dense stands of pinyon-juniper would increase from 3.6 to 22.8 animal units per section after 20 years, assuming a potential herbage production of 650 pounds per acre, essentially all of which is palatable to livestock. The study areas were primarily on sedimentary soils (Barr 1956).

Aro (1971) evaluated pinyon-juniper conversion attempts made in four States. He found considerable variation in the success of removing the overstory and in improving forage yields. Forage yield increases varied from zero on some chained areas to 1,600 pounds per acre on some burned and reseeded areas.

The effect of pinyon-juniper control on livestock carrying capacity has not been precisely measured (or reported) in Arizona. Juniper control and reseeding efforts on sedimentary soils have been estimated to have increased livestock carrying capacity several times (Chilson 1964, Robinson 1965). Grazing capacity has increased three to four times on favorable sites (personal communication with Albert Thatcher, SCS, Phoenix).

Wildlife

The increase in forage plants after pinyon-juniper removal has a potential of benefiting game populations (Barr 1956). Initial results of

Arizona Game and Fish Department studies suggested, however, that controlling pinyon-juniper has had a largely neutral effect on deer populations, although some control procedures may be more beneficial than others (Jantzen 1966). Reynolds (1964) concluded that pinyon-juniper reduction could be done in a manner that maintained or improved habitat conditions for deer and elk.

Utilization and Value of Overstory Species

The potential economic products from the pinyon-juniper woodlands are quite varied. Fenceposts, firewood, lumber, veneer, particleboard, charcoal, pulp, extractive chemicals, pinyon nuts, and Christmas trees are some of the potential uses. Because of high per-unit costs woodland products have been harvested to only a limited degree, although recent energy shortages have greatly stimulated the harvest of firewood. Thus, pinyon-juniper control to date has not had significant economic impact on overstory products (Barger and Ffolliott 1972, and Barr 1956).

Methods of Overstory Removal

Large areas typically have been treated by cabling or chaining, while bulldozing or pushing has been used widely to remove individual trees. Hand clearing by axe and saw has been utilized in special situations. Broadcast burning has been reasonably successful where the pinyon-juniper stands were heavy and topography aided in fire control. Individual-tree burning and the use of herbicides have been utilized on a limited scale. The Nonstructural Range Improvements Handbook (USDA-FS 1970b) and the Guide to Improvement of Arizona Rangeland (Arizona Interagency Range Technical Sub-Committee 1973) provide excellent background information on selection of pinyon-juniper control techniques and range seeding methods.

The costs of initial tree removal have varied widely by method and situation (Aro 1971, Barger and Ffolliott 1972, Cotner 1963, Warskow 1967). Additional expenses are often involved, such as followup hand cutting of small trees missed by a chaining or cabling operation, slash burning, and seeding for forage species (Chilson 1964, Warskow 1967, Worley and Miller 1964). An optimum stand-selection procedure for juniper control has been developed by Jameson (1971). It takes into account the probable rate of overstory density increase, and rate of change of treatment costs for

different treatments as the overstory changes.

A discussion of current juniper control costs can be found in a later section titled "Benefit-Cost Analysis."

Vegetation Type Description

Pinyon-Juniper of the Southwest

The pinyon-juniper type occupies over 60 million acres in western and southwestern United States (USDA-FS 1958). Fifty-one million acres occur in the Four-Corner States of Arizona, New Mexico, Colorado, and Utah (Dortignac 1960). The primary distribution of the type in these States corresponds to the distribution of pinyon (fig.2). Estimates of the acreage in Arizona vary from 12 million (Spencer 1966) to 14 million (Arnold and others 1964). The pinyon-juniper type covers over one-fourth of the Salt-Verde River Basin (Barr 1956) (fig.3).

This type is commonly referred to as a woodland rather than a forest because the trees are generally small and below sawtimber size. The climate of the pinyon-juniper type is rather severe for tree growth, characterized by low precipitation, hot summers, high wind, low relative humidity, very high evaporation rates, and much clear weather and intense sunlight. The annual precipitation for the type generally varies from 12 to 18 inches, with local areas up to 20 inches.

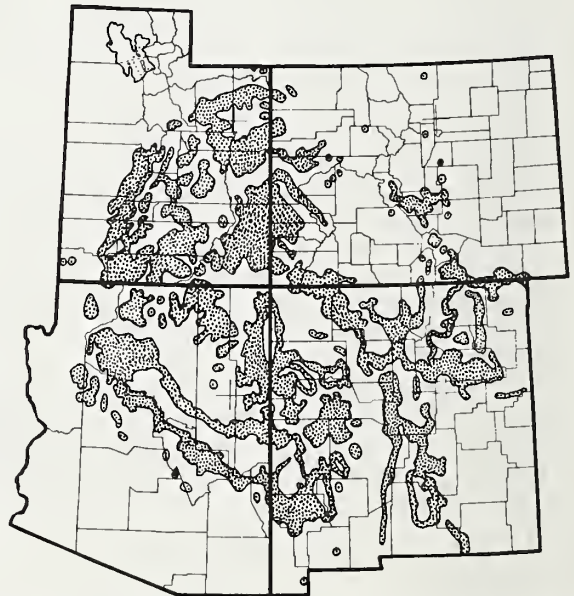


Figure 2.—Distribution of pinyon in the Four-Corner States (from Little 1971).

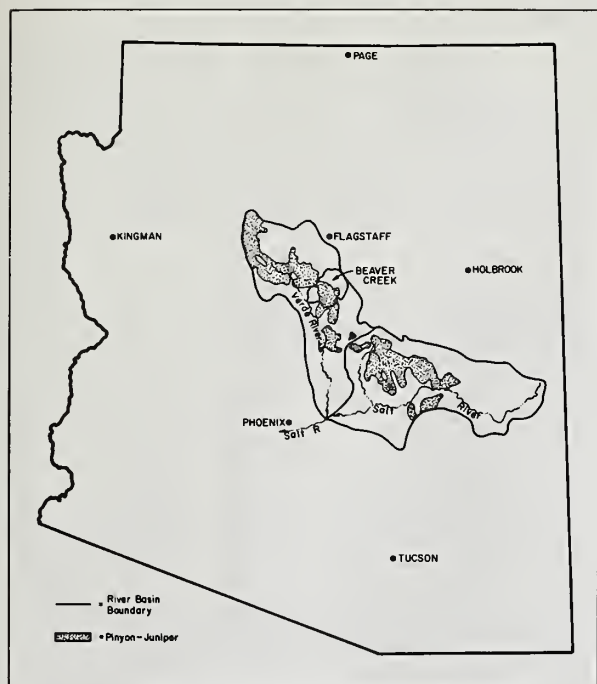


Figure 3.—Distribution of the pinyon-juniper type in the Salt and Verde River Basins (adapted from Spencer 1966).

In Arizona the pinyon-juniper woodland lies primarily between the elevations of 4,500 and 6,500 ft. It is flanked by ponderosa pine forests above and by desert shrub, chaparral, or semiarid grassland types below. Soils, which have developed from a wide variety of parent materials, vary from shallow and porous to moderately deep and very fine textured (Dortignac 1960, USDA-FS 1965, Williams and Anderson 1967).

The most consistent species in the woodland type is pinyon, although in Arizona one or several *Juniperus* species will usually dominate the stand. The three most common junipers in Arizona are Utah, one-seed, and alligator. The distribution of the juniper species and their related understory species appears to correspond to climate variations (Arnold and others 1964).

Pinyon-Juniper of the Beaver Creek Watershed

Physiography.—Sloping mesas and breaks, steep canyons, and valleys characterize the pinyon-juniper type on Beaver Creek. The bedrock underlying the area consists of igneous rocks of volcanic origin, and below that sedimentary rocks of Kaibab, Coconino, and Supai Formations.

The pilot watersheds in the Utah juniper subtype have a range in average elevation of 5,200 to 5,500 ft. The soils are developed from volcanic materials, primarily basalts. The predominant soil is Springerville very stony clay. The typical profile is 44 inches deep, with a clay texture throughout (Williams and Anderson 1967).

The pilot watersheds in the alligator juniper subtype have a range in average elevation of 6,200 to 6,400 ft. The soils have also developed from volcanic materials. In addition to the Springerville soils, the Gem soils are also important. The typical Gem profile is similar in depth to the Springerville, but is lighter textured and has a greater structural development (Williams and Anderson 1967).

Climate.—Annual precipitation ranges from 12 to 24 inches with an average of 18 inches in the Utah subtype, and 16 to 27 inches with an average of 20 inches in the alligator subtype (table 1). Respectively, 11 and 12 inches come during the months of October through April as snow and rain. Mean annual temperature in the Utah and alligator juniper subtypes has been 56°F and 50°F, respectively (table 1).

Vegetation.—The two pinyon-juniper subtypes on the Beaver Creek watershed represent the lower and upper woodland zones in the sub-Mogollon region of the Inland Southwest (Lowe 1961). In both subtypes pinyon is a minor component. Tree densities are given in tables 2 and 3.

Vegetation occurring under the pinyon-juniper overstory includes grasses, forbs, half-shrubs, and shrubs. The production of understory plants in the alligator subtype is greater compared to the Utah subtype, due largely to a lower overstory density. The range condition of the untreated areas is “very poor” in the Utah subtype and “poor” in the alligator subtype.

Wildlife.—The pinyon-juniper vegetation type on Beaver Creek supports a good variety of big game, carnivores, small game, rodents, and birds (Neff 1974) during all or a portion of the year. Rocky Mountain mule deer is the primary species sought by hunters, although a number of other game animals and game birds are hunted as well.

Water Yield Improvement Tests on the Beaver Creek Watershed

Treatments Applied

The woodland overstory was removed by

Table 1.--Average precipitation and temperatures in the two pinyon-juniper subtypes, Beaver Creek watershed

MONTH	PRECIPITATION ¹		TEMPERATURE ²					
	Utah juniper subtype	Alligator juniper subtype	Utah juniper subtype			Alligator juniper subtype		
			Maximum	Minimum	Mean	Maximum	Minimum	Mean
	<i>Inches</i>		<i>°F</i>					
October	1.02	1.06	72	43	58	66	38	52
November	1.64	2.00	60	33	46	54	29	41
December	2.10	2.55	52	26	39	48	23	36
January	1.47	1.85	51	24	38	46	21	34
February	1.30	1.33	54	27	41	48	23	35
March	1.90	2.07	58	31	44	51	25	38
April	1.40	1.42	66	38	52	60	31	45
May	.37	.53	76	45	61	68	38	53
June	.36	.39	86	54	70	80	46	63
July	1.53	1.58	91	62	76	85	54	70
August	2.70	2.63	87	60	73	81	53	67
September	2.40	2.79	82	54	68	76	47	61
Mean annual	18.19	20.23			56			50

¹Based on 11 years of record.

²Based on 15 years of record.

Table 2.--Number of trees per acre, by species and diameter--Utah juniper subtype

Diameter (Inches)	Utah juniper	Pinyon	All species
<i>- - Stems per acre - -</i>			
0.1 - 4.9	40.8	13.3	54.1
5.0 - 8.9	42.8	.9	43.7
9.0 - 12.9	20.5	.8	21.3
13.0 - 16.9	8.6	1.0	9.6
17.0 - 20.9	3.9	0	3.9
21.0+	2.2	0	2.2
Total	118.8±26.4	16.0±14.4	134.8±29.1
<i>- - - Percent - - -</i>			
	88	12	100

Table 3.--Number of trees per acre, by species and diameter--alligator juniper subtype

Diameter (Inches)	Alligator juniper	Utah juniper	Ponderosa pine	Pinyon	Gambel oak	All species
<i>----- Stems per acre -----</i>						
0.1 - 4.9	92.9	11.3	6.8	3.8	0	114.8
5.0 - 8.9	10.8	3.1	1.2	0	.2	15.3
9.0 - 12.9	2.0	.2	.8	.1	.2	3.3
13.0+	2.1	.2	.3	0	0	2.6
Total	107.8±20.7	14.8±7.5	9.1±2.2	3.9±3.1	0.4±0.3	136.0±22.1
<i>----- Percent -----</i>						
	79	11	7	3	T	100

three different techniques—cabling, herbicide, and felling—in an attempt to increase water yield.

The cabling treatment, applied to watershed 1 (Utah subtype) in 1963, was similar to that extensively applied in the Southwest for range improvement. The larger trees were uprooted by a heavy steel cable pulled between two bulldozers (fig. 4); small trees missed by the cable were hand chopped, slash was burned, and the

area was seeded with a mixture of forage species (Brown 1965).

The herbicide treatment of watershed 3 (Utah subtype) in 1968 consisted primarily of a helicopter application of 2½ pounds of picloram and 5 pounds of 2,4-D per acre (fig. 5). The intent was threefold; (1) to reduce transpiration losses by killing trees, (2) to reduce evaporation losses by leaving the dead trees standing to reduce windspeed and insolation, and (3) to avoid the



Figure 4.—Uprooting trees by pulling a cable between two tractors on watershed 1.



Figure 5.—Applying herbicide by helicopter to kill trees on watershed 3.

problem of overland water flow being trapped in soil pits created when trees are uprooted (Brown 1971). No forage species were seeded. One year previously, 2,4-D and 2,4,5,-T had been applied to watershed 3 to desiccate the tree foliage preparatory to a burning treatment. Because the burning attempt was unsuccessful, it was decided to kill the trees in place by chemicals rather than by fire.

The felling treatment on watershed 6 (alligator subtype) was conducted in 1965. The trees were cut by powersaws (fig. 6) and left in place, thus avoiding pitting and other types of soil disturbance. Stumps of alligator juniper were treated with polychlorinated benzoic acid to reduce sprouting; shrub live oak was treated initially with fenuron and later with picloram; Gambel oak sprouts were treated with a dormant-season basal spray of 2,4,5-T (Brown 1971). No forage species were seeded.

The mechanical treatments on watersheds 1 and 6 resulted in nearly 100 percent overstory removal. Approximately 83 percent of the overstory stand on watershed 3 was killed by the herbicide application,³ with vigor of many of the



Figure 6.—Felling alligator juniper on watershed 6.

remaining trees severely reduced. A higher survival rate among smaller trees suggested that they benefited from the protection of the larger trees.

Measurement Techniques

New techniques in stream gaging have been utilized to accurately measure the broad range of debris-laden discharges carried by the streams. A concrete trapezoidal flume was designed for use on the small watersheds. The design was a modification of a Washington State College flume, adapted to Beaver Creek conditions (Robinson 1961). The watersheds are organized into an experimental design to provide a basis for statistical evaluation of changes in streamflow. Watersheds within each vegetation type are paired, with some scheduled for treatment and others retained untreated as statistical controls. Following pretreatment calibration, one watershed in each pair is treated. These methods are described by Kovner (1956), Kovner and Evans (1954), and Wilm (1943.)

The sediment data were obtained by means of the catchment basins and splitting devices illustrated and described by Brown and others (1970). In addition to measurements of total sediment, suspended sediment concentration has been sampled on all watersheds.

³Larson, Frederic R. Posttreatment inventory of Utah juniper watershed No. 3 on Beaver Creek. Unpubl. Off Rep., 1970. Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.

Chemical water quality samples have been collected under different conditions. Most samples were of runoff from melting snowpack and were taken from the flume, either dipped or with a DH-48 sampler. A few were collected from the sediment storage tanks below splitter installations. Samples were stored in glass containers and sent to a USGS (U.S. Geological Survey) laboratory. Analysis included pH, electrical conductivity, total dissolved solids, hardness, silica as SiO₂, calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, chloride, and fluoride. Iron, manganese, boron, nitrate, and phosphate were also included in the analysis of some samples.

The range inventories primarily involved plot measurements of plant production and utilization, and transect measurements of condition and trend. Measurements were made periodically at 10 locations within each watershed. On five 9.6-ft² plots at each location, herbage production was determined for each species by weight estimate and checked by clipping and weighing (Pechanec and Pickford 1937a). Forage utilization was determined by the ocular-estimate-by-plot method (Pechanec and Pickford 1937b). Range condition, including ground cover and plant frequency, was determined by the method of Parker (1954).

Big-game populations and use have been measured primarily by the Arizona Game and Fish Department. Changes in occupancy of the watersheds by deer and elk are estimated from counts of fecal droppings on plots superimposed on the tree overstory inventory points.

Forage preferences of deer are determined by observing the plants eaten by tame deer under different treatment conditions. Production of preferred wildlife forage is determined by combining species yields and preference information.

Streamflow Response

Responses of annual and winter streamflow to vegetation treatments on the pinyon-juniper watersheds are presented in table 4. Mean annual streamflow for the untreated condition is based on variable periods of record for the given watersheds, and has been adjusted by covariance to minimize variation due to climate and other factors not associated with treatment. Responses for individual years following treatment are determined by subtracting the flow predicted by covariance from the actual. Average treatment responses are expressed quantitatively in inches and as a percent of the pretreatment mean. Probability levels at which the current responses are statistically significant are indicated.

The only significant response in annual streamflow is from the herbicide treatment on watershed 3. This response increase averages 0.45 inch or 65 percent over a 4-year period, and is statistically significant at the 2.5 percent level. The streamflow response from the felling treatment on watershed 6 was 0.38 inch or 14 percent over a 7-year period, which is not significant at the 10 percent level. (Although a

Table 4.--Summary of treatment effects on annual and winter streamflow for three Beaver Creek pinyon-juniper watersheds, by subtypes

Watershed, by subtype, treatment, year treat- ment completed, and streamflow recorded	Mean stream- flow ¹	Difference between actual and predicted streamflow by years following treatment										Mean difference ²		Level of significance ³
		1st	2d	3d	4th	5th	6th	7th	8th	9th				
UTAH JUNIPER SUBTYPE:	<i>Inches</i>	-	-	-	-	-	-	-	-	-	-	<i>Inches</i>	<i>Percent</i>	
Watershed 1-- Cabled, slash burned 1963														
Annual streamflow	0.77	-0.36	-0.04	0.28	-0.08	0.18	0.12	(⁴)	0.03	0.01	0.02	3	NS	
Winter streamflow	.62	.07	-.11	.22	-.04	.13	.06	.02	-.02	-.04	.03	5	NS	
Watershed 3-- Herbicide, no removal or burning 1968														
Annual streamflow	.69	.39	1.19	.04	.17						.45	65	0.025	
Winter streamflow	.52	.31	.85	.03	.11						.32	62	.025	
ALLIGATOR JUNIPER SUBTYPE:														
Watershed 6-- Felled, no burning, regrowth restricted 1965														
Annual streamflow	2.63	.53	.90	-.12	.17	.75	.25	.21			.38	14	NS	
Winter streamflow	2.49	.46	.90	-.09	.17	.29	.26	.16			.31	12	NS	

¹Adjusted by covariance for years 1958-72 for watersheds 1 and 3; 1961-72 for watershed 6.

²Adjusted by covariance.

³NS indicates nonsignificance at the 0.10 level.

⁴Due to quality of data, response for water year 1970 was not included in covariance analysis. Streamflow response for 1970 was probably between +0.71 and +0.90 inch.

treatment response for watershed 6 was indicated, the streamflow calibration was not sufficiently precise to detect a 14 percent change in water yield.)

Watershed 1, where overstory was removed by cabling, has had a 9-year evaluation period. The seventh-year response was not included in the covariance analysis because the major portion of this annual runoff came during the storm on September 5, 1970. During this storm, the flume was overtopped and the stream-gage rating was affected by debris blocking the flume. The estimated range of annual response during this year is from 0.7 to 0.9 inch, nearly four times larger than the next highest response (table 4). Because of the questionable quality of data and because most of the runoff came during such an extreme event (estimated to have a recurrence interval of 100 to 150 years), Water Year 1970 was left out of the calculated mean response. The remaining years of data for watershed 1 show no significant change in streamflow due to treatment.

The winter streamflow response (table 4) is similar to the annual streamflow response, and also shows that only the herbicide treatment on watershed 3 significantly increased water yield.

The explanations for the lack of change in water yields following the cabling of watershed 1 are largely speculative. A combination of water entrapment by soil pits (Skau 1961), heavy growth of herbaceous vegetation (mainly forbs and half-shrubs), and greater evaporation losses probably compensated for the reduction in transpiration of the overstory. The primary reasons for the striking difference in response between the herbicide and the cabling treatments have not been experimentally determined. There is little doubt, however, that the lack of soil pitting and the reduction of solar radiation and windspeed by the standing dead trees play a role in the water yield increase from watershed 3.

Soils on watershed 3 deeper than 12 inches did not dry to the permanent wilting point from the first winter following treatment until the late summer of 1972, about 4 years. In untreated areas, the soils were dry much of each year. Similar responses have been observed with small plot studies of herbicidal vegetation control elsewhere (Johnsen 1970). The lack of rapid soil moisture loss on watershed 3 may be due to the replacement of deep-rooted trees with generally shallow-rooted annual plants which would not deplete moisture below the surface foot of soil. The dryness of the soil during the fourth summer after treatment may be due to either an increase in deeper rooted plants or to the very dry preceding winter. When the sub-

surface soil remains moist, less precipitation is needed to wet the soil sufficiently for runoff to occur.

The mean annual runoff from the untreated alligator juniper watersheds was 4.3 ± 1.0 inches with a runoff efficiency of 21 percent, compared to 0.8 ± 0.3 inch from the untreated Utah juniper watershed for a runoff efficiency of 4 percent. The portion of the total runoff occurring in the period of October through April was 96 percent and 74 percent, respectively (figs. 7 and 8). Streamflow efficiency for the seasonal period October-April was 34 and 6 percent, and for May-September was 2 and 3 percent for the alligator and Utah juniper, respectively.

Even though water yield efficiency is higher on the alligator juniper than on the Utah juniper watersheds, the felling treatment on watershed 6 (alligator juniper) has not resulted in a significant streamflow response. The characteristically low overstory density of the alligator juniper subtype on Beaver Creek may provide little opportunity to create a measurable water yield increase with any type of vegetative manipulation. Areas of alligator juniper with stands approaching the densities of the Utah juniper watersheds may have the potential, however, to give a measurable water yield increase upon tree removal.

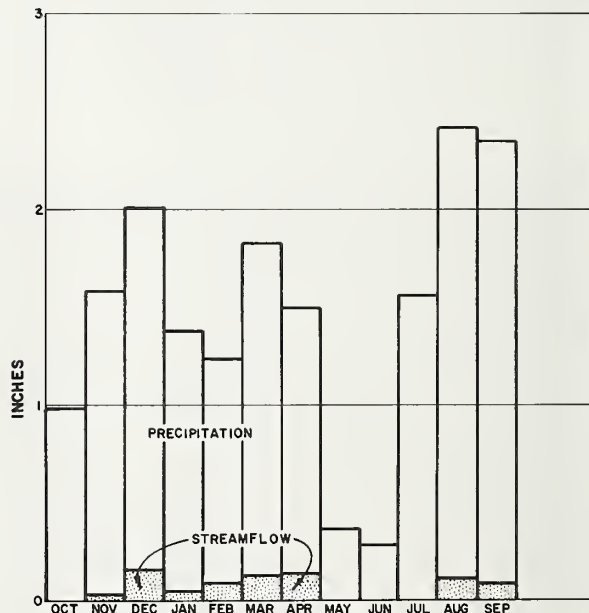


Figure 7.—Average monthly streamflow and precipitation in the Utah juniper subtype on Beaver Creek. Streamflow data are from watershed 2; precipitation data are from three gages on watersheds 2 and 3.

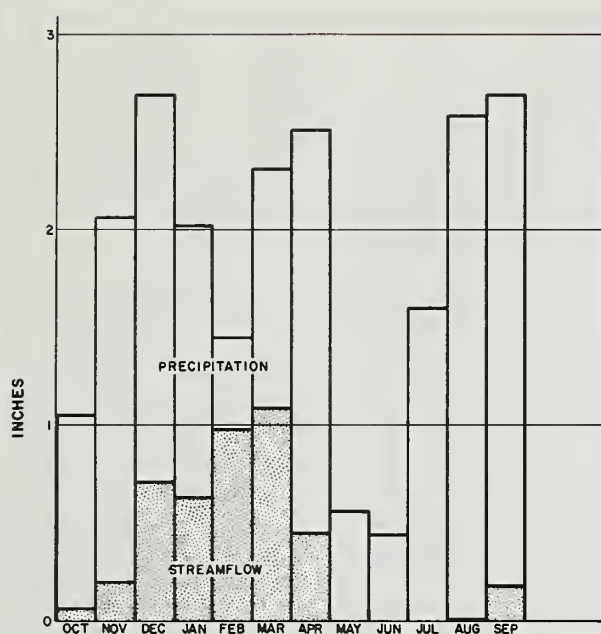


Figure 8.—Average monthly streamflow and precipitation in the alligator juniper subtype on Beaver Creek. Streamflow data are from watersheds 4 and 5; precipitation data are from three gages on watersheds 4, 5, and 6.

Attempts to predict streamflow from the Beaver Creek pinyon-juniper watersheds using simple regression models have been only moderately successful. Since two treatments produced no detectable water yield increase, there was little basis for describing the effect of over-story removal on water yield. Precipitation was the only variable significantly contributing to the predictions of streamflow. Winter precipitation was a better predictor than annual precipitation, and was as good as using winter and summer precipitation as independent predictors. The equations are:

Utah juniper watersheds—

Annual runoff $Y = 0.25X - 2.00$; $r = 0.70$

Winter runoff $Y = 0.28X - 2.50$; $r = 0.77$

Alligator juniper watersheds—

Annual runoff $Y = 0.94X - 8.08$; $r = 0.90$

Winter runoff $Y = 0.96X - 8.50$; $r = 0.89$

where

Y = inches of runoff, and

X = inches of winter precipitation.

Winter precipitation is a fairly good predictor of annual runoff because 74 percent of the annual runoff from the Utah juniper subtype and about 96 percent from the alligator juniper subtype occur during the winter period.

Progress in modeling water yields from other southwestern pinyon-juniper watersheds has been reported by the U.S. Geological Survey (Myrick 1971). Concerning the other water yield models available, the Stanford Watershed Model (Crawford and Linsley 1966) is not suited for application on small watersheds. The USDA model (Holtan and Lopez 1971) is not applicable in this area because it does not account for snowmelt runoff. Water Yield 1 (USDA-FS 1972) may be applicable to this area, but has not been available for testing. Leaf and Brink's (1973) hydrologic model will be tested once it has been modified to function in areas with shallow or intermittent snowpacks. Rogers' (1973) model has not been tested in the pinyon-juniper type pending more thorough evaluations of results from the ponderosa pine type. While testing of the BURP Model (USDA-FS 1968) on Beaver Creek has been considered, all model evaluation has been delayed until completion of an overall determination of models needed to provide information for management of the southwest forest ecosystems.

Flood Peak Response

A major storm which struck Beaver Creek in September 1970 (Baker and others 1971) provided an opportunity to assess the effect of the pinyon-juniper treatments on flood peaks. Total precipitation for this 24-hour storm period ranged from 3.9 to 4.9 inches on the six pinyon-juniper watersheds. Peak runoff discharges ranged from 400 to 700 $\text{ft}^3/\text{s}/\text{mi}^2$ (cubic feet per second per square mile) and total runoff from 0.76 to 2.00 inches. Treatment responses (table 5) were estimated graphically, based on the relationship between peak discharge and 60-minute precipitation intensity (fig. 9). These estimates are based on the assumption that the change in runoff response of treated watersheds from the untreated relationship represents the response to vegetation manipulation. These estimates are not subject to statistical verification, however. Table 5 also contains the estimated recurrence intervals for the observed peak discharges.

The largest response was from the cabling treatment on watershed 1. The increase in peak discharge due to treatment was estimated to be 250 $\text{ft}^3/\text{s}/\text{mi}^2$, or 60 percent.

Sediment Yield Response

Mean annual sediment yields from the untreated pinyon-juniper watersheds sampled on Beaver Creek (13 station years) have varied from 0.01 to 0.27 ton per acre, with an average of 0.10 ton per acre over a 9-year period of record.

Table 5.--Summary of treatment effects on flood peaks for the September 1970 storm on the pinyon-juniper watersheds

Watershed, by subtype, treatment, and year treatment completed	Flood peak			Estimated recurrence interval ¹	Since treat- ment
	Estimated for untreated conditions	Actual	Estimated difference due to treatment		
	- - - - -	$Ft^3/s/mi^2$	- - - - -	- Years -	
UTAH JUNIPER SUBTYPE:					
Watershed 1-- Cabled, slash burned 1963	450	700	250	100-150	7
Watershed 3-- Herbicide, no removal or burning 1968	400	500	100	50	2
ALLIGATOR JUNIPER SUBTYPE:					
Watershed 6-- Felled, no burning, regrowth restricted 1965	550	600	50	40	5

¹As determined by the USGS, Tucson, Arizona, using regionalized peak discharge from the Beaver Creek watersheds.

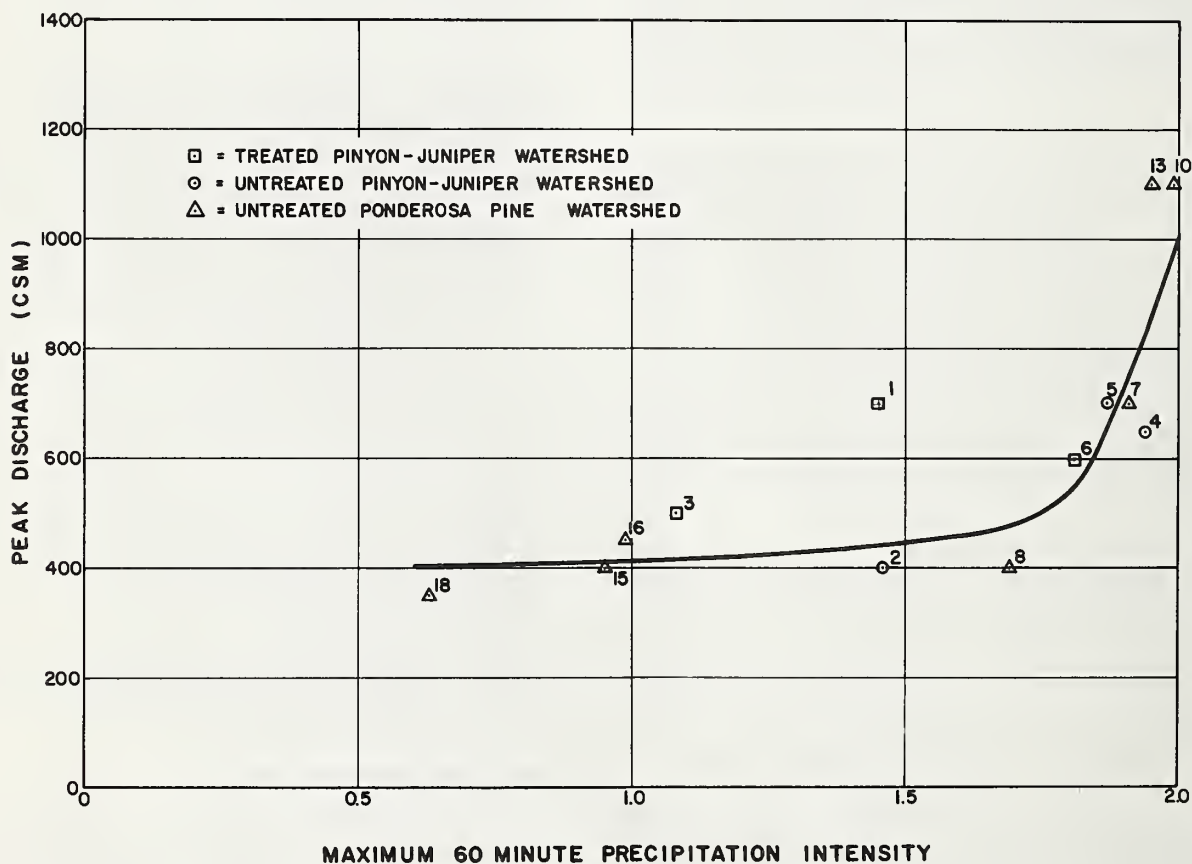


Figure 9.—Relationship of peak discharge to precipitation intensity on Beaver Creek for the 1970 Labor Day storm.

Mean winter sediment yields from untreated watersheds have ranged from a trace (less than 0.005 ton per acre) to 0.27 ton per acre, with an average of 0.07 ton per acre; summer yields have ranged from 0 to 0.27 ton per acre, with an average of 0.03 ton per acre. These mean values indicate that over 50 percent of the sediment in the pinyon-juniper type is generated during the winter season. This seasonal relationship is even more striking when one considers that eight of nine summer seasons had sediment yields of 0.005 ton or less per acre. The remaining summer (1970) had a sediment yield of 0.27 ton per acre from untreated watershed 4 as the result of a storm which had an estimated recurrence interval of 100 years.⁴

Mean annual sediment yields from treated pinyon-juniper watersheds on Beaver Creek have varied from a trace to 1.1 tons per acre on a cabled watershed, and from a trace to 0.08 ton per acre on a herbicide-treated watershed. Because of the short period of record (13 station years) and confounding due to treatment intensity, storm frequency, and climatic variation, a mean cannot realistically be calculated to generalize the treated condition in the pinyon-juniper type on Beaver Creek.

The largest sediment yield of 1.1 tons per acre was produced on a cabled watershed during the September 1970 storm, which produced a peak discharge of 800 ft³/s/mi² with an estimated recurrence interval of 100 to 150 years. This watershed received a maximum 30-minute precipitation intensity of 2.17 inches per hour and a total storm precipitation of 4.06 inches. The only peak discharge in the pinyon-juniper type on Beaver Creek which exceeded this amount during the period of record was on the same watershed in 1964, 1 year after its cabling treatment. The discharge of 1,000 ft³/s/mi² produced a sediment yield of 0.33 ton per acre. The storm producing this discharge occurred on August 3, 1964, and had a total precipitation of 1.59 inches over a 45-minute period, with a maximum 30-minute intensity of 3.14 inches per hour. Apparently the greater total rainfall in 1970 was a factor in producing over three times more sediment than the storm event in 1964.

Based on records obtained during the past 9 years on Beaver Creek, and from knowledge of sediment losses resulting from various treatment intensities and storm frequencies, it appears that sediment yields of 1 to 2 tons per acre are approaching the maximum sediment loss potential for watersheds with similar physical characteristics and climatic regimes in the pinyon-juniper type. We also conclude that

there appears to be no meaningful change in sediment yield after either cabling or applying herbicide in the pinyon-juniper type.

We have attempted to predict sediment yield from Beaver Creek pinyon-juniper watersheds using simple regression models. Runoff was the only variable which contributed significantly to prediction of sediment yields. Seasonal runoff was found to be a better predictor of seasonal sediment yields than annual runoff was for predicting annual sediment yields. The equations are:

Winter sediment—

$$Y = 0.02X - 0.01; r = 0.70$$

Summer sediment—

$$Y = 0.13X; r = 0.99$$

where

Y = tons per acre of sediment, and

X = inches of seasonal runoff.

Since runoff was the primary factor influencing sediment yields, and overstory removal had little effect on runoff from the pinyon-juniper watersheds, the above equations are assumed to apply equally well to treated and untreated areas.

Water Quality Response

Seven primary water quality samples have been analyzed from pinyon-juniper watershed runoff. Samples taken on watersheds 1 and 3 on April 6, 1964, (table 6) represent the entire spring runoff, which was caught by the sample splitters and stored in sediment tanks. The TDS (total dissolved solids) content of the water from the treated watershed was 148 mg/l or 2.4 times as great as from the untreated watershed (62 mg/l). The increases in amounts of Ca, Mg, Na, K, and HCO₃ were proportionally different. Water from watershed 1 contained approximately 3.5 times as much sulfate and chloride as did watershed 3, but the silica and nitrate contents were not greatly different.

On the basis of the March 1964 runoff record and the analyses reported here, watershed 1 produced 0.1 inch of runoff per acre and lost 3.26 pounds of dissolved salts per acre. In contrast, for the same series of events, watershed 3 produced 0.003 inch of runoff and lost 0.04 pound of dissolved salts per acre.

Runoff from watersheds 2 and 3 were both dip-sampled at the flumes in January 1969. Watershed 3 had been treated with herbicide in 1968, whereas watershed 2 remained untreated. The TDS in the runoff from watershed 3 was 117 mg/l as compared to 104 mg/l from untreated watershed 2 (table 6).

⁴Based on estimates made by USGS, Tucson, Arizona.

Table 6.--Analyses of water samples from the pinyon-juniper subtypes, Beaver Creek watershed

Watershed, by subtype, and date sample taken	pH	Conduc- tivity	TDS	SiO ₂	Ca	Mg	Na	K	HCO ₃	SO ₄	Cl	NO ₃	Fe	Mn	F	B	CO ₃	Hardness
		EC×10 ⁶	-	-	-	-	-	-	-	-	Mg/l	-	-	-	-	-	-	MgCaCO ₃ /l
UTAH JUNIPER SUBTYPE:																		
Watershed 1--																		
April 6, 1964	7.3	251	148	9.6	33	8.9	4.2	3.6	120	21	1.1	0.4	0.22	--	0.4	--	0	119
Watershed 2--																		
January 26, 1969	7.0	163	104	13	22	14.1	14.5	13.5	96	7	2.5	--	0	--	.2	--	0	72
Watershed 3--																		
April 6, 1964	7.1	99	62	8.3	13	3.3	2.2	1.5	51	6.2	.9	.7	.32	--	.3	.03	0	46
January 26, 1969	8.0	182	117	15	25	15.2	14.0	13.0	98	12	4.5	--	0	--	.2	--	0	84
September 19, 1970	8.3	266	161	15	38	9.6	4.7	3.4	175	.5	3.2	0	.01	0.02	.1	--	0	130
Mean	7.5	192	118	12	26	6.2	3.7	2.8	108	9.3	2.4	.4	.18	.02	.2	.03	0	90
ALLIGATOR JUNIPER SUBTYPE:																		
Watershed 5--																		
March 8, 1966	6.7	74	54	15	7.3	2.4	3.7	1.8	34	5.8	.4	.2	.99	--	.1	0	0	28
Watershed 6--																		
March 8, 1966	6.5	89	68	18	9.7	3.4	3.0	2.7	41	9.1	1.2	.4	.35	--	.2	0	0	38
Mean	6.6	82	61	16	8.5	2.9	3.4	2.2	38	7.6	.8	.3	.67	--	.2	0	0	33

¹Estimated.

Only two water quality analyses were made in connection with the alligator juniper felling on watershed 6 in 1965. Water samples were dipped from the flumes of watershed 6 and control watershed 5 in March 1966. The runoff represented both rain and snowmelt. The water from the treated watershed contained 68 mg/l TDS as compared to 54 mg/l TDS from the control. The individual ion concentrations varied between the two samples in about the same proportion as the TDS except for chloride, which was three times higher on watershed 6.

Water produced from the juniper watersheds generally exceeded minimum quality standards (National Technical Advisory Committee 1968) for irrigation, public water supply, and for aquatic life. However, the iron content on some of the samples exceeded the recommended standard for aquatic life and for drinking water. All samples had extremely low SAR (sodium absorption ratio) values. All electrical conductivity values (μ mho/cm) were low (less than 100) on the alligator juniper watersheds, while two of three posttreatment samples from the Utah juniper watersheds showed a slight deterioration in respect to irrigation. The latter still exceeds drinking water and aquatic life standards, and its use would be unrestricted for irrigation.

Water from the Utah juniper watersheds was moderately hard and from the alligator juniper watersheds it was soft, based on the classification of Durfor and Becher (1964, p. 27). Suspended sediment was determined on samples taken concurrently with water quality samples.

Correlation analysis showed no consistent relation between suspended sediment and TDS.

The total dissolved solids in the runoff water average 118 mg/l from the Utah juniper subtype and 61 mg/l from the alligator juniper subtype, compared with 46 mg/l from ponderosa pine watersheds (H. Brown et al. 1974). These concentrations do not reflect greater total dissolved material from the Utah juniper watersheds, however. Winter runoff is least from the Utah juniper, and this lower volume of runoff overshadows the concentration of dissolved solids when calculating the total dissolved solids leaving the area.

In addition to the above analyses, 24 paired runoff samples collected for herbicide residue determinations were also tested for nitrate content. These dip samples, taken at the flumes of Utah juniper watersheds 2 and 3 from 1969 through 1972, showed no evidence of increased nitrate contamination of surface runoff water. Usually, nitrate concentration was below the lowest reliable detection limit of the methods used, about 0.5 mg/l. The greatest amount detected was 36 mg/l in water from the untreated watershed 2, an amount approaching the limit set for potable water. Much of the nitrate which would be expected to be released from the dead trees on watershed 3 may have been used on site by the abundant annual vegetation which appeared following treatment.

Information on herbicide residues can be found in a later section titled "Efficacy of Herbicide Applications."

Vegetation Response and Changes in Potential Livestock Carrying Capacity

The production of understory plants in the untreated alligator juniper subtype averaged 518 pounds per acre, about 2.7 times the production of the Utah juniper subtype (194 pounds per acre) largely as a result of differences in tree density. The original tree basal area and tree crown cover for the pinyon-juniper watersheds (see fig. 1) were:

Watersheds by subtype	Tree basal area (Ft ² /acre)	Crown cover (Percent)
Utah juniper:		
1	(No data)	28±2
2	57±8	30±2
3	53±7	28±2
Average	55±5	29±1
Alligator juniper:		
4	17±2	12±1
5	19±3	14±1
6	24±3	13±2
Average	20±2	13±1

Cabling, hand chopping remaining trees, and burning of slash effectively removed the overstory from watershed 1. Because of this thorough overstory removal, the area is expected to remain dominated by herbaceous vegetation for a number of years. The estimated increase in annual production of grasses, forbs, and half-shrubs on watershed 1 is approximately 700 pounds per acre or 614 percent. The

largest increases were in perennial grasses and in forbs and half-shrubs (table 7). The success of the seeded forage species was quite erratic (fig. 10). The understory species which are defined as livestock forage (USDA-FS 1970a) on watershed 1 increased an estimated 180 pounds per acre or nearly 300 percent as a result of treatment.

A commonly used conservative conversion of available forage to livestock carrying capacity is 1,000 pounds of forage per AUM (animal unit month). However, if we assume the range is grazed seasonally rather than yearlong, 750 pounds of forage per AUM is more realistic because shattering loss will be much less during the grazing period. At 40 percent utilization, the livestock carrying capacity would then be about 0.02 AUM/acre before treatment and 0.13 AUM/acre after treatment.

The actual increase in forage plants, and therefore in relative carrying capacity, can vary from near zero after 10 years (Clary 1971) to perhaps 1,000 pounds per acre or more in favorable years if sufficient effort is put into the reseeding attempt. Results of seeding trials in the Utah juniper subtype on Beaver Creek indicate side-oats grama, western wheatgrass, pubescent wheatgrass, and yellow sweetclover are well adapted and high yielding (personal communication with Fred Lavin, ARS, Flagstaff). Side-oats grama and pubescent wheatgrass planted in 1966 yielded 1,431 and 2,315 pounds per acre, respectively, in 1969, and 1,109 and 809 pounds per acre on 1970. Western wheatgrass yielded 1,012 and 1,353 pounds during the same years. A large potential yield of

Table 7.--Summary of treatment effects on herbaceous and shrubby plant production¹ from the two pinyon-juniper subtypes, Beaver Creek watershed

Watershed, by subtype, treatment, and year treatment completed	Plant group	Production for untreated conditions	Difference between actual and predicted production by years following treatment								Level of significance ²	
			1st	2d	3d	4th	5th	6th	7th	Average		
----- Pounds per acre -----												
UTAH JUNIPER SUBTYPE:												
Watershed 1-- Cabled, slash burned	1963	Perennial grasses	29	111	130	200	--	81	162	--	137	0.05
		Annual grasses	3	29	10	0	--	28	3	--	14	NS
		Forbs and half-shrubs	73	1,032	260	339	--	231	849	--	542	0.05
		Shrubs	9	1	-2	2	--	4	32	--	7	NS
Watershed 3-- Herbicide, no removal or burning	1968	Perennial grasses	12	19	21	47	55	--	--	--	36	0.10
		Annual grasses	6	145	83	15	48	--	--	--	73	0.10
		Forbs and half-shrubs	74	8	535	468	515	--	--	--	382	0.05
		Shrubs	17	-5	-21	-18	-20	--	--	--	-16	NS
ALLIGATOR JUNIPER SUBTYPE:												
Watershed 6-- Felled, no burning, regrowth restricted	1965	Perennial grasses	282	73	126	49	78	16	362	84	113	0.05
		Annual grasses	0	0	0	0	0	0	0	0	0	NS
		Forbs and half-shrubs	347	104	241	55	34	6	219	281	134	0.15
		Shrubs	0	0	0	0	0	0	0	0	0	NS

¹All values, in pounds per acre, were obtained as follows: (1) the pretreatment ratio was determined between the treated watershed and its control watershed; (2) this ratio was applied to the posttreatment control mean to obtain an estimate of posttreatment production for untreated conditions; (3) the ratio was applied to individual year data of the control and the result subtracted from the observed production to provide an estimate of annual change. The significance of treatment response was determined by covariance.

²NS indicates nonsignificance at the 0.15 level.



Figure 10.—Lovegrass was successfully established in some areas (a) while other areas (b) were dominated by broom snakeweed and annual goldeneye.

forage is indicated from seeding Utah juniper ranges in the Beaver Creek area. Native forage plants can also increase moderately within 10 years, but only if a basic forage component is present at the time of tree removal (Clary 1971).

The herbicide treatment of watershed 3 also resulted in significant increases in production of understory plants (table 7), but the pattern differed from cabled areas, which were quickly dominated by forbs and half-shrubs if perennial

grasses were not present. The first year following the herbicide application the watershed was a waving field of red sprangletop, an annual grass (fig. 11). This species made 58 percent of the understory production, causing a significant increase in total yields 1 year after treatment. Total forb and half-shrub production was similar to the pretreatment period, but broom snakeweed, rough menodora, and sulfur eriogonum (half-shrubs) were largely replaced by spurge and common sunflower (annuals). The abundance of red sprangletop was reduced by one-half the second year, but the forb-half-shrub component increased 535 pounds per acre. Goosefoot, Russianthistle, prickly lettuce, and conyza were important in the second-year composition. Prickly lettuce was the most important single species on watershed 3 for the next several years. The estimated increase in understory yield following the herbicide treatment was 576 pounds per acre, or 528 percent. This figure does not include the first posttreatment year, which was eliminated due to possible carryover herbicide effects.

The production of forage plants on watershed 3 before treatment was almost nil. Since few native forage plants were present and no artificial seeding was done, production of desirable forage has changed little except for small local areas. It is estimated that actual forage production has increased about 65 pounds per acre. The few forage plants existing on the area have very high vigor, however, suggesting that if this treatment were applied to an area with a good residual stand of perennial grasses and other forage species, the livestock carrying capacity would be much improved.

The felling treatment on watershed 6 effectively removed the tree overstory. However, the followup control of alligator juniper and Gambel oak regrowth (sprouts), and the original control of shrub live oak by chemicals was less successful. In 1969, 4 years following treatment, 24 of 130 circular plots with 8.2 ft radius were stocked with woody plants.⁵ Without additional followup treatment, this watershed will again in a few years have an aspect of a lightly stocked woodland.

The felling of alligator juniper, rather than bulldozing, resulted in minimum disturbance to the native grass stand. No forage species were seeded. The average increase in total plant production on this felled watershed was 242 pounds per acre, or 38 percent. The yields of forage plants increased 45 percent, or about 130

⁵Larson, Frederic R. Reproduction survey of clearcut alligator juniper Watershed No. 6 on Beaver Creek. Unpubl. Off. Rep., 1969. Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.

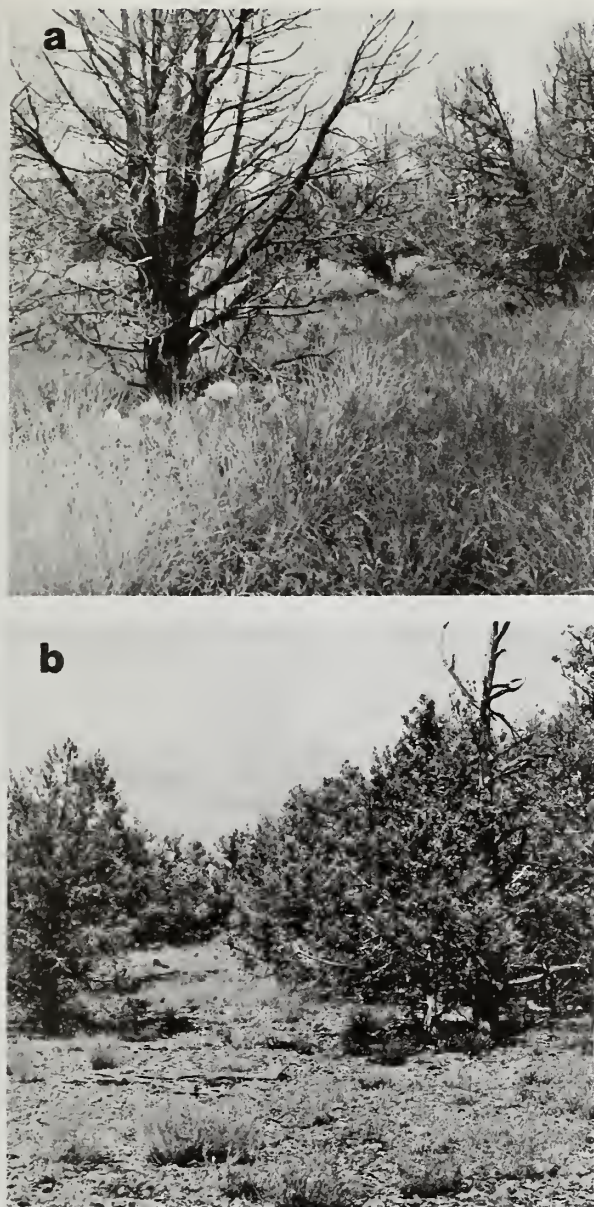


Figure 11.—Comparison of understory plants in 1968: (a) red sprangletop on watershed 3; (b) half-shrubs on an adjacent area of watershed 2.

pounds per acre (Clary 1974)—a potential grazing capacity increase of 0.07 AUM/ acre.

Several relationships have been developed for estimating the effect of pinyon-juniper overstory on understory plant production in Arizona (Arnold and Schroeder 1955, Arnold and others 1964, Clary 1971, Jameson 1967). Jameson (1971) developed perhaps the most generally useful relationships, involving different grass growth-forms and soils. Other rela-

tionships of potential herbage yields to soil characteristics and topography are also described (Clary 1964).

Because the soils and topography within the individual vegetation subtypes on Beaver Creek are rather uniform, they were not utilized to predict herbage yields in the present simple regression models. These regressions, which use watershed-years as a data base, do not provide precise predictions of herbage yields, but they do give an indication of what can be expected.

Tree basal area and summer precipitation are used to predict herbage yields (grasses, forbs, and half-shrubs) for the two subtypes. The regressions are:

Utah juniper watersheds—

$$Y = 346.4 - 129.4X_1 + 28.3X_3; r = 0.85$$

Alligator juniper watersheds—

$$Y = 593.3 - 357.0X_1 + 75.4X_2; r = 0.72$$

Alligator juniper watersheds—

$X_1 = \log (\text{tree basal area} + 2)$

$X_2 = \text{June to August precipitation}$

$X_3 = X_2/X_1$

These equations illustrate measured differences in plant response between the subtypes. When there is no overstory, the herbaceous plant yields are similar (fig. 12). However, an overstory depresses herbage yields much more in the Utah juniper subtype than in the alligator juniper subtype. Likewise, in the Utah juniper subtype the herbaceous plants under a tree stand are less responsive to differences in precipitation than are herbaceous plants in the alligator juniper subtype. Some of the reasons for this difference in plant response, primarily soil related, are discussed by Jameson (1971) and Jameson and Dodd (1969).

The above regressions illustrate what can be expected for total herbage yields. The actual animal carrying capacity of an area depends very highly upon plant composition. Therefore, forage plant composition must be determined before regression estimates can be used to estimate potential animal carrying capacity.

Habitat Change and Wildlife Response

Deer numbers have changed considerably in the pinyon-juniper on Beaver Creek (Neff 1972a, 1972b). Mean annual deer densities in the Utah juniper subtype have decreased from about 36 per section (640 acres) in 1960 to between 4 and 5 per section since 1962. This reduction was part of a regional decline in deer populations (Wallmo 1964). In the alligator juniper subtype deer numbers decreased from approximately 20 deer per section in 1960 to 4 or less by

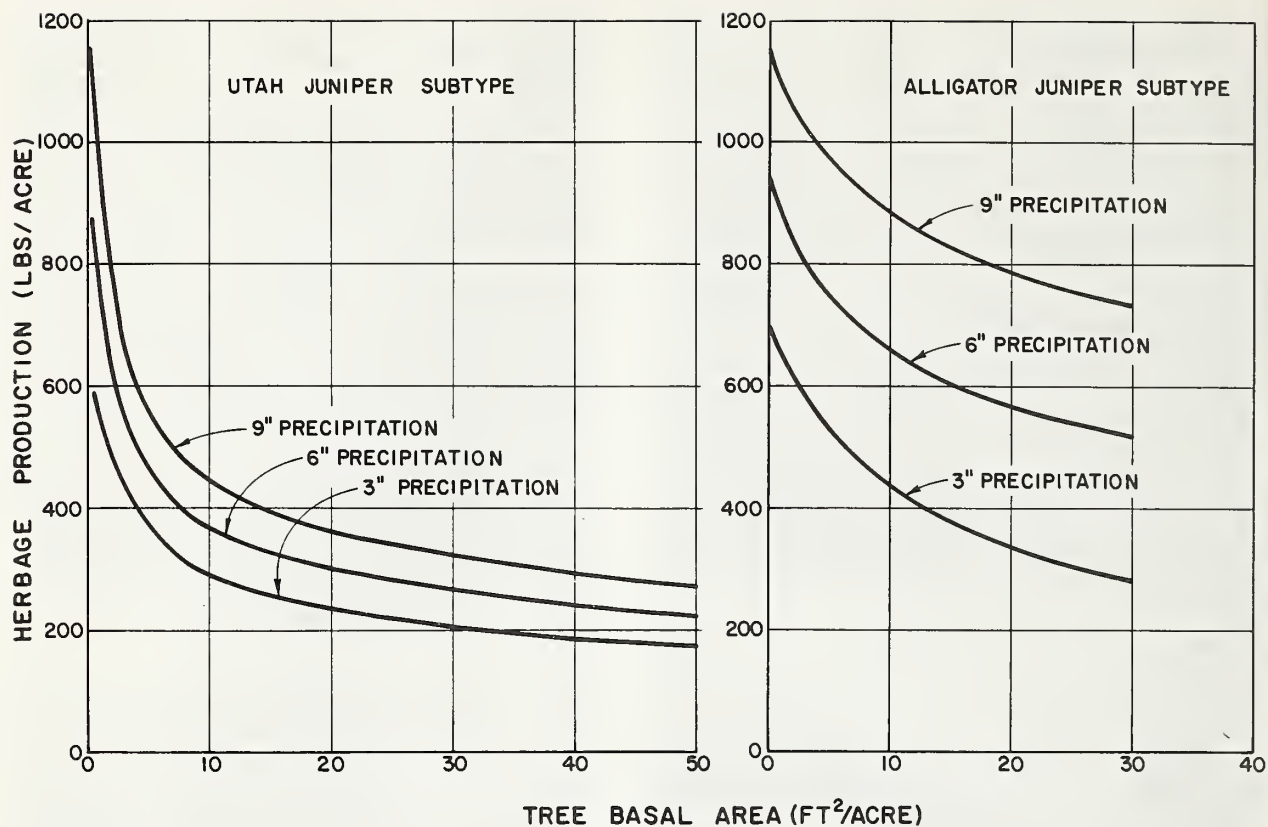


Figure 12.—Relationship of herbage production to tree basal area and summer precipitation in the two pinyon-juniper subtypes.

1964. The mean density from the mid-1960's to the early 1970's has been about two deer per section.

Elk make little use of the Utah juniper subtype on Beaver Creek except during extremely wet winters. The mean annual elk density of the alligator juniper is approximately one per section.

The forage plants on untreated areas that are most preferred by deer include, in order of contribution to the diet (Neff 1974):

	Percent of diet
Mountainmahogany	21
Eriogonum, Wright	9
Oak, shrub live	6
Cliffrose	5
Oak, Gambel	4
Ceanothus, desert	4
Lettuce, prickly	3
Squirreltail, bottlebrush	2
Buckthorn, hollyleaf	2
Bundleflower, James	2

Additional desirable plants such as crested wheatgrass, pubescent wheatgrass, yellow sweetclover, and clover are often seeded in conjunction with land treatments.

Production of preferred forbs, half-shrubs, and shrubs averages approximately 60 pounds per acre in the Utah juniper subtype and 90 pounds per acre in the alligator juniper subtype.

Forbs, half-shrubs, and shrubs, which are moderately to highly preferred by deer (Neff 1974), increased significantly as a result of two of the three treatments (table 8). The largest increase came on watershed 3 which had the least cover of perennial grasses.

The effect on wildlife cover also appears to be important. The one vegetation treatment on Beaver Creek which deer have tended to avoid is the felling treatment, even though the production of preferred forage increased somewhat. The situation on this watershed was unique in that the pinyon-juniper cover surrounding it had been removed in the late 1950's. The treatment had the effect of removing an island

Table 8.--Summary of treatment effects on forbs and shrubs preferred by deer on the two pinyon-juniper subtypes, Beaver Creek watershed

Watershed, by subtype, treatment, and year treatment completed	Deer forage production ¹		Level of signifi- cance ²
	Untreated conditions	Response due to treatment	
<i>Pounds per acre</i>			
UTAH JUNIPER SUBTYPE:			
Watershed 1-- Cabled, slash burned 1963	40	90	NS
Watershed 3-- Herbicide, no removal or burning 1968	83	³ 342	0.05
ALLIGATOR JUNIPER SUBTYPE:			
Watershed 6-- Felled, no burning, regrowth restricted 1965	79	41	0.10

¹See table 7 for method of calculation.

²NS indicates nonsignificance at the 0.15 level.

³Beginning with second posttreatment year.

of cover (standing trees) surrounded by a large clearing. Thus, big game apparently avoid this particular area because of a lack of cover, even though a fair amount of slash remains. The same treatment on a watershed surrounded by live pinyon-juniper might have produced a far different result (Neff 1972b).

Deer use of watershed 1 remained essentially unchanged after the cabling treatment. Even though the watershed is up to one-half mile across, deer use was uniform across the area. Apparently there was sufficient shrub live oak and other low cover to satisfy the deer during the periods they ranged the large clearings (Neff 1972a).

The posttreatment deer use of herbicide-treated watershed 3 was moderately light, but it was considered to be a positive response because it increased annually following treatment (Neff 1972b). This response is apparently the result of greatly increased production of preferred forage (table 8), and the retention of cover (standing dead trees).

Of special importance to deer on this winter range is the increase in supply of late winter and early spring feed (personal communication with Don J. Neff, Ariz. Game and Fish Dep., Flagstaff) in the form of early grasses and preferred forbs on watershed 3. In 1972 the production of early feed was over four times that of the control watershed, or nearly 250 pounds per acre.

Elk use of the Beaver Creek pinyon-juniper watersheds has been too light to adequately assess their reaction to treatments. The responses of other wildlife species to the pinyon-juniper treatments have not been evaluated; an intensive wildlife evaluation program was initiated on the Beaver Creek ponderosa pine watersheds in 1972 (Brown and others 1974). Many smaller wildlife species will respond more strikingly

than deer, however. A great many species of birds, for example, forage for food primarily in tree foliage (Balda 1969). When the trees are removed, these species will go elsewhere, and be replaced by ground-feeding species. Good populations of mourning doves, a species highly valued by bird hunters, are often observed on cabled areas.

Efficacy of Herbicide Applications

Herbicide was broadcast by helicopter on about 300 acres of watershed 3 in August 1968. Twenty acres were not treated. A 40-acre buffer strip between watersheds 2 and 3 was treated by spraying individual trees with backpack, motorized mist blowers. A commercially available mixture of triisopropylamine salts of picloram and 2,4-D was applied at the rate of 2½ pounds of picloram and 5 pounds of 2,4-D in a volume of 10 gallons per acre with a water carrier. The application rates were excessive for killing the junipers, but were used to aid studies of picloram residue in soils and runoff water. Picloram was used because of its promise of possible widespread use, based on other studies in juniper control.

On the entire watershed 83 percent of the Utah junipers were killed, including 96 percent killed on the broadcast area, 70 percent on the individual-tree buffer area, and very little damage on the untreated areas. On the treated areas the surviving trees either contained small amounts of live foliage or were small trees growing under the protective canopy of larger trees. Pricklypear cactus was severely damaged and has not recovered after several years. Shrub live oak and pinyon were severely damaged initially, but showed marked recovery within 2 or 3 years. Cliffrose was moderately damaged, but recovered quickly. Side-oats grama and other established perennial grasses were undamaged. Sulphur eriogonum and rough menodora were slightly damaged, but both of these, along with broom snakeweed, had been severely damaged by an earlier application of 2,4-D and 2,4,5-T esters. The remaining broom snakeweed was killed by the picloram-2,4-D application.

Numerous annual forbs and grasses invaded the watershed after the picloram-2,4-D treatment, although by 1972 perennial grasses, especially side-oats grama, were becoming more apparent over much of the watershed. Some of the annual forbs grew exceptionally large during the initial 2 years after treatment. Sunflowers, for example, which normally grow 3 or 4 ft tall along the roadsides, grew to 10 ft or more on the treated areas. This unusual growth may have

been due to increased moisture available, and possibly nutrients released by the dead junipers.

Forbs showed marked symptoms of picloram damage during midsummer of the first year, indicating the picloram was below the initial foot or so of the soil surface. Symptoms were slight by the third year and were not observed during the fourth year after treatment, indicating the picloram had disappeared from the root zone of the annual forbs.

The net effect of the herbicide treatment on vegetation was to convert a juniper-dominated tree stand to a stand of annuals. Usually, conversion by mechanical means has changed tree stands into half-shrub stands dominated by snakeweed. Small plot tests at other locations on Beaver Creek indicate the response of watershed 3 to herbicidal vegetation control is typical of the Utah juniper type. Perennial plants should become established eventually without the snakeweed stage of secondary succession. The presence of both spring- and summer-growing annuals indicates the possibility of producing both spring- and summer-growing perennials in these areas. How this growth pattern would affect water yields is not known.

Picloram concentration of surface runoff waters was determined during each flow period following treatment. The highest concentration detected was 0.32 p/m (part per million) during the initial flow after treatment. By the first spring after application, picloram concentrations were less than 0.01 p/m. No picloram has been detected in runoffs since October 1971.

It is estimated that about 1.3 percent of the picloram applied has left the watershed in runoff. Of this, 90 percent left within the first 7 months after treatment, during which time 13.2 inches of precipitation fell and about 14 acre-ft of water had run off the treated watershed. By the time the last picloram was detected, 58 inches of precipitation had fallen and 46.8 acre-ft of water had left the watershed. On one occasion picloram was detected 3.5 miles downstream, but at a concentration of only 0.002 p/m (minimum detectability is 0.001 p/m). Usually, picloram was not detected further than one-fourth mile downstream. There seemed to be little difference in picloram concentration due to type of runoff (snowmelt versus storm flow). Samples taken during flow periods gave similar results throughout the flow period.

These results are similar to those of high-rate applications of picloram in other studies. Lower rates of application would yield lower amounts of picloram in the runoff water, and for shorter periods.

The individual-tree treated area always had lower amounts of picloram in the runoff water

than the broadcast area. The maximum picloram concentration detected from this area was 0.19 p/m during the initial flow period after treatment; within a year picloram was barely detectable in the runoff and has not been detected in flows since February 1971.

Picloram in the soil has declined to barely detectable amounts within 4 years. The initial amounts averaged 2.5 pounds of picloram per acre in a 4-ft soil mantle; within 3 years this was reduced to about 0.8 pound, and within 4 years to less than 0.02 pound. This reduction was reflected by the forbs growing on the watershed. During the initial year after treatment, forbs showed marked symptoms of picloram damage by midsummer. During the second and third summers these symptoms became less pronounced and occurred later in the summer. Very few symptoms appeared during the fourth summer. Results have been similar in other studies of high-rate application. With lower application rates, the picloram disappears from the soil much more quickly.

It must be remembered that the rate of application of the picloram was excessive for juniper control, and the inclusion of 2,4-D in the treatment was due to material availability not to increase the degree of juniper control. Less than a pound of picloram would be sufficient to control the Utah juniper. This lower rate should be competitive, costwise, with mechanical methods. Other herbicides can control junipers, but, like picloram, they are not presently registered for use except in experimental studies.

After the alligator junipers were felled on watershed 6 in the summer of 1965, polychlorinated benzoic acid in diesel oil was sprayed onto the stumps of all trees under 16 inches in diameter and on larger trees as needed to reduce sprouting. Shrub live oak stumps were treated with pelleted fenuron in 1965. Gambel oaks were treated with 2,4,5-T in diesel oil before bud break in the spring of 1966 (Brown 1971).

About half the stumps of alligator juniper under 16 inches diameter, the size class most likely to sprout, were killed by the polychlorinated benzoic acid treatment. About a fourth of the stumps of this size class were missed and untreated, and about another fourth had been poorly treated and sprouted. Shrub live oak showed little damage from the initial fenuron treatment, with indications of poor herbicide distribution around the oak clumps.

The residual juniper sprouts, Gambel oak sprouts, and shrub live oak were treated with a mixture of picloram and 2,4-D at a concentration of 1 pound picloram and 2 pounds 2,4-D per 10 gallons of water in August and September 1968. Kill of the alligator juniper was satisfactory. That of the oaks was variable.

Benefit-Cost Analysis

The basic intent of this Paper is to examine the impact of vegetation manipulation on multiple uses of the land in the pinyon-juniper type, with emphasis on the Beaver Creek Pilot watersheds. Effects of watershed treatments on surface water yield, livestock forage production, and big-game habitat are summarized in table 9. The effects have not been very impressive. Impacts of these treatments on other multiple uses of these lands, such as recreation and esthetics, have not yet been discussed.

Recreation use is limited primarily to hunting, although there are other forms of dispersed recreation such as four-wheel-drive and motorcycle pleasure riding, horseback riding, and hiking. The concern for esthetics would come primarily from these users unless the treatments would be in a travel influence zone. Complete overstory removal, as on watersheds 1 and 6 (cabling and felling treatments), would be detrimental both recreationally and esthetically. Most people, however, would probably consider a partial removal properly designed to be a plus

from both recreation and esthetic standpoints.⁶ Presently, watershed 3 (herbicide treatment) would be preferred by hunters because it is attractive to deer, but from an esthetic viewpoint it would probably be disliked. The negative visual aspects of the defoliated trees were not adequately offset by the new growth of herbaceous plants.

Since incremental changes in water yield and forage production can be productively used, the amount of these benefits should be identified. The value of additional water can be analyzed from two viewpoints—those of the primary user, and the Salt River Valley Water Users Association which administers the dams in the Salt and Verde Basins and handles water distribution. Additional water production from the Salt-Verde Basin will be demanded by irrigated agriculture for feed grain and forage produc-

"There is a cooperative study now underway at the University of Arizona entitled: "Development and validation of an unbiased method to quantify natural beauty of forest landscapes" that will provide a procedure to measure the esthetic dimension.

Table 9.--Summary of treatment effects on surface water yield, livestock forage production, and big-game habitat on the two pinyon-juniper subtypes, Beaver Creek watershed

Watershed, by subtype, treatment, and year treatment completed	Post-treatment	Products		
		Water yields	Livestock forage	Big-game habitat
	<i>Yrs</i>		<i>Lb/acre</i>	
UTAH JUNIPER SUBTYPE:				
Watershed 1-- Cabled, slash burned 1963	9	No significant change	+180	+preferred plants (deer) -cover ¹ No apparent effect on deer use
Watershed 3-- Herbicide, no removal or burning 1968	4	+1/2 inch	+65	+preferred plants (deer) No apparent effect on cover +deer use of watershed
ALLIGATOR JUNIPER SUBTYPE:				
Watershed 6-- Felled, no burning, regrowth restricted 1965	7	No significant change	+130	+preferred plants (deer) -cover ² -deer and elk use

¹Because watershed 1 was surrounded by Utah juniper and considerable shrub live oak cover was present nearby, reduction in tree cover on the watershed was not a severe deterrent to deer use.

²The alligator juniper surrounding watershed 6 had been removed several years prior to treatment and little lateral cover was present, which had a negative effect on deer use.

tion. All other users of water such as municipal, industrial, and high-value crops already have their demand satisfied with existing supplies. Based on 1972 conditions, the ability-to-pay value for water used in irrigating feed grain and forage crops would have been \$11.20 (T. Brown et al. 1974). The value of additional surface water to the Salt River Project is the savings in costs resulting from the replacement of pump water. For the first 25,000 acre ft, this amount is estimated at \$10.30 per acre-ft (Salt River Project cost records, 1972) and consists of savings in operating and capital costs, and reduction in depletion rate of ground-water table. An additional value which must be added is the power revenue the water would generate if the additional flow came in above Roosevelt Dam. In 1972, this would have amounted to \$2.48 per acre-ft. Based on the above information, the maximum primary value of additional water is \$13.68 per acre-ft delivered to the user. Applying that value to the half-inch increase on watershed 3, we have a value of 57 cents per acre per year. This assumes that all onsite increases in water yield would reach the user, which is not likely.

Before forage production can be measured in dollar terms, it must first be converted to grazing capacity. A conservative conversion commonly used is 1,000 pounds of forage per AUM. If we assume the range is grazed seasonally rather than yearlong, however, so that shattering loss is reduced, 750 pounds of forage disappearance per AUM (ovendry) is more realistic. Based on 40 percent utilization, the following gains in potential grazing capacity could be expected:

Watershed	AUM / acre
1	0.11
3	.03
6	.07

There are several ways to identify the incremental value of increased carrying capacity. These include the grazing fee paid, the capitalized value of Forest Service permits plus the grazing fee, the comparable private lease rate, and the marginal value of additional grazing capacity to existing ranches. For these watersheds the latter approach is the best, since a rancher currently operates in this area. Not all ranch costs increase proportionately with the addition of more cattle, however, so the costs per AUM are less than average of the ranch's herd. Examples of costs which do not increase proportionately are property tax, insurance, utilities, and building depreciation. To arrive at an expected monthly return for the additional cattle, a representative market price needs to be identified and structural improvement costs

and operating costs deducted. This was done in a recent study (O'Connell and Boster 1974) for 1972 conditions; the net returns per AUM amounted to \$5.82.

Values determined by the other methods are approximately the following (1972 conditions):

Forest Service grazing fee ⁷	\$0.72 per AUM
Forest Service grazing fee plus capitalized value of permit ⁸	2.30 per AUM
Comparable private lease rate ⁹	3.94 per AUM

Several publications discuss the merits of these different approaches in detail (Dickerman and Martin 1967, Martin and Jefferies 1966, Regional Research Project W-79 1968, Smith and Martin 1972).

Applying the \$5.82 figure to the gains in grazing capacity results in per-acre returns of 64 cents per acre for watershed 1, 17 cents per acre for watershed 3, and 41 cents for watershed 6.

If 7.0 percent is the appropriate capitalization rate, a 64-cent annuity would capitalize to \$9.14 per acre ($64 \text{ cents} \div .07 = \9.14), a 17-cent annuity would capitalize to \$2.42 per acre, and a 41-cent annuity would capitalize to \$5.86 per acre. Considering the returns discussed, the maximum allowable per-acre treatment costs are \$9.14 for watershed 1, \$10.57 for watershed 3,¹⁰ and \$5.86 for watershed 6. The noneconomic effects would not tend to enhance the feasibility of the treatment.

The capitalized values, as calculated above, represent allowable costs for initial treatments and any followup maintenance that may be required. If initial cost was \$15.00 per acre and a \$1.50 per-acre maintenance cost was required every 10 years, the total cost (1972 value) would be \$16.49. To cover a maintenance cost of \$1.50 every 10 years, a fund of \$1.49 would have to be set aside at 7.0 percent interest. The accumulated interest would be sufficient to cover a 10-year periodic maintenance cost of \$1.50 into perpetuity.

⁷Based on 1972 grazing fees on the Coconino National Forest.

⁸Based on information developed by Martin and Jefferies (1966) and updated to 1972.

⁹Based on commercial rate the Forest Service charges; it is developed annually by the USDA Statistical Reporting Service, and represents comparable private lease rates in the Western States in 1972.

¹⁰The 57-cent annuity for expected water-yield increases on watershed 3 was also capitalized at 7.0 percent interest and equaled \$8.14.

The actual per-acre costs were \$19.41 (Worley and others 1965) for watershed 1, \$36.90 for watershed 3,¹¹ and \$45.00 (Miller 1971) for watershed 6. Thus juniper control is not economically feasible for areas that have responses similar to these watersheds.

The range carrying capacity of the experimental watersheds appears to be below the average for conditions in the Southwest. According to 1972 figures,¹² average grazing capacities of pinyon-juniper ranges (defined as having at least 75 percent pinyon-juniper cover type) on the National Forests of Southwest varied from 0.25 AUM per acre for ranges in good condition to 0.04 AUM per acre for ranges in poor condition. Even after juniper is removed, the carrying capacity would be 0.23 AUM per acre for watershed 6 and 0.13 AUM for watershed 1 (assuming 40 percent utilization throughout the watersheds).

A more successful juniper control project would expect to have increases in forage production of from 400 to 600 pounds per acre (ovendry) beginning 2 to 3 years after conversion. Some areas where this increase has occurred include the Canjilon project on the Carson National Forest and the Bar T Bar, 13 Mile Rock, Buckhorn, and Deadwood projects on the Coconino National Forest. Discussions with range managers of the Fort Apache Indian Reservation indicate these yield increases have been attained on some of their better projects also.

Using the same conversion factors discussed above and assuming an increase in forage production of 500 pounds per acre, the gain in potential grazing is 0.27 AUM/acre. This expected increase in grazing capacity is similar to that experienced on the Bar T Bar Ranch for 8 years following conversion. Using a value of \$5.82 per AUM and assuming cattle were put on the converted area 3 years after conversion, the capitalized value would be \$19.15 per acre. Other ranching benefits of removing junipers are reduced labor costs and faster weight gain of yearlings. Cotner and Kelso (1963) reported an 18-cent gain per acre for these benefits. Updating these figures to 1972 (which brings them to 35 cents per acre) and capitalizing them, these added benefits would amount to \$4.33 per acre. The total benefit to ranching amounts to

$\$19.15 + \$4.33 = \$23.48$ per acre (7.0 percent interest rate) for the more successful conversions. If a 10.0 percent interest rate is used, the total benefit is \$15.56 per acre.

The surface water yield response of the experimental watersheds appears to be typical; there is no strong evidence of surface water yield improvement from treating pinyon-juniper watersheds.

Other effects of conversion that should be evaluated are impacts on water quality, sediment yields, wildlife habitat, and esthetics. If the conversion is done and maintained properly and if good range management practices are followed, there can be plus effects for some of these factors. The problem is the number of "ifs". The evidence to date has been mixed.

Beaver Creek costs are atypical because of the small size of the watersheds and experimental nature of the treatments. The most complete cost analysis on juniper control in the Southwest was done by Cotner (1963). He found that number of trees per acre and tree height explained most of the site variation in costs. Based on Cotner's analysis and using 1972 cost estimates, a bulldozing operation would cost between \$9 and \$13 per acre for pushing and piling a moderately dense stand of 125 trees per acre that are 12 to 15 ft high. Followup cleaning and slash burning costs vary from \$2 to \$4 per acre (Forest Service records, Worley and Miller 1964), and seeding costs are estimated at \$4.20 per acre (Warskow 1967, updated to 1972). A minimum maintenance allowance would be \$1.50 per acre every 10 years. Pulling all these items together—pushing and piling, followup cleaning and burning, seeding, and maintenance—a moderately priced juniper conversion for an operational size project would cost about \$19.69 per acre (1972 conditions).

Other major mechanical methods used for controlling juniper include cabling and the use of a tree crusher. Cabling was used extensively in the fifties and the early sixties, but most of the good sites for cabling have already been converted. The cost for cabling is about half that of pushing and piling, but it is not as effective. Although a tree crusher is the most effective, it cannot be used in rocky areas, which includes much of Arizona. The cost is slightly higher than pushing and piling.

Although herbicide treatment is the only method that increased water yield from the juniper type, current restrictions on use of herbicides preclude consideration of them in the immediately foreseeable future.

The literature review and the above analysis leads us to conclude that, based on 1972 technology, costs, and values, identifiable economic benefits and costs come out about even for the

¹¹Estimated from local USDA Agricultural Research Service records.

¹²Springfield, H.W. Characteristics and management of southwestern pinyon-juniper ranges. (Manuscript in preparation, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)

more successful juniper control projects. At a 7.0 percent interest rate there is a net positive difference of \$3.79 per acre, while at a 10.0 percent interest rate the difference is negative (-\$4.13). This means that for the more successful projects, benefits will just cover costs. Each project should be examined on its own merits, however.

Some other considerations that should be examined on individual projects include whether limited investment dollars can bring a higher return elsewhere, and whether the juniper control project can be made a multiproduct sale.

Conclusions

These conclusions apply specifically to the Arizona pinyon-juniper vegetation type on volcanic-derived soils along the Mogollon Rim. Evidence in the literature suggests, however, that similar results and conclusions may also be expected in other southwestern areas.

- Conventional mechanical methods of pinyon-juniper removal cannot be expected to increase water yields in the Utah juniper subtype.

- Overstory removal by herbicide appears to be the only vegetation treatment that is likely to increase water yield from Utah juniper watersheds. Picloram effectively controlled the pinyon-juniper overstory and changed the successional pattern of herbaceous plants. Only 1.3 percent of the picloram left the watershed in runoff water, and it ceased to be detectable in the water within 3 years after application. Picloram was barely detectable in the soil mantle after 4 years.

- The areas of low tree densities in the alligator juniper subtype do not show promise for increasing water yield.

- The felling treatment on watershed 6 could have been advantageously modified to retain the large mature and overmature alligator juniper trees. This modification would have resulted in sizable cost savings (Miller 1971, Miller and Johnsen 1970), provided an esthetically appealing savanna aspect, retained more wildlife cover, and may have maintained greater long-term early forage on these spring-fall ranges (Clary and Morrison 1973).

- There has been no meaningful change in

sediment yields as a result of overstory removal. Five of the seven pinyon-juniper water-quality samples met drinking water, aquatic life, and irrigation water standards. Two samples were slightly high in iron to conform to the drinking water standard. Apparent differences in water quality among watersheds were not validated by statistical methods because of inadequate sample size.

- Overstory removal in the Utah juniper subtype will result in a severalfold increase in herbage production. The value of this increase for livestock or wildlife use is highly variable. The potential increase in livestock carrying capacity on many Utah juniper areas is nearly 0.5 AUM per acre, but this potential is rarely approached. An increase of about 0.21 to 0.32 AUM per acre is indicated for the more successful pinyon-juniper conversion projects. Much lower increases are typical when pinyon-juniper conversions are attempted on low potential sites or when poor seeding techniques are used.

- The response by deer to the pinyon-juniper watershed treatments was, on the average, neutral. All treatments increased the production of preferred plants, but cover should be available nearby for the deer to maintain use of the areas. Deer have responded positively to the herbicide treatment, which resulted in a fourfold increase in palatable herbaceous forage plants and maintenance of relatively heavy cover. Elk use of the pinyon-juniper watersheds was not heavy enough to allow an evaluation of their response. The response of other wildlife species has not been measured.

- Current restrictions on herbicide use (the only treatment that increased water yield) and the negative esthetics of standing dead trees may limit juniper control to mechanical methods for the foreseeable future. Since mechanical methods are not likely to produce measurable water yield increases, the only economic returns are from range values. Analysis of a number of pinyon-juniper conversion attempts suggests that under 1972 economic conditions the more successful projects just about break even from a benefit-cost standpoint. Projects which are less successful than the best will produce a negative net return. Therefore, considerable planning and forethought should precede any future pinyon-juniper conversion attempt.

- Experience with herbicides on Beaver Creek and with fire elsewhere suggests that these two methods may be the most fruitful areas for future juniper control research from the combined standpoints of water production, forage production, deer response, and economics.

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Common and Botanical Names of Plants Mentioned

Common Names

Botanical Names

Grasses

Grama, side-oats	<i>Bouteloua curtipendula</i> (Michx.) Torr.
Lovegrass	<i>Eragrostis</i> spp.
Sprangletop, red	<i>Leptochloa filiformis</i> (Lam.) Beau.
Squirreltail, bottlebrush	<i>Sitanion hystrix</i> (Nutt.) J.G.Smith
Wheatgrass, crested	<i>Agropyron desertorum</i> (Fisch.) Schult.
Wheatgrass, pubescent	<i>Agropyron trichophorum</i> (Link) Richt.
Wheatgrass, western	<i>Agropyron smithii</i> Rydb.

Forbs and Half-Shrubs

Bundleflower, James	<i>Desmanthus cooleyi</i> (Eaton) Trel.
Clover	<i>Trifolium</i> spp.
Conyza	<i>Conyza canadensis</i> (L.) Cronq.
Eriogonum, sulfur	<i>Eriogonum cognatum</i> Greene
Eriogonum, Wright	<i>Eriogonum wrightii</i> Torr.
Goosefoot	<i>Chenopodium</i> spp.
Lettuce, prickly	<i>Lactuca serriola</i> L.
Menodora, rough	<i>Menodora scabra</i> A. Grey
Russianthistle	<i>Salsola kali</i> L.
Snakeweed, broom	<i>Gutierrezia sarothrae</i> (Pursh) Britt. & Rusby
Spurge	<i>Euphorbia</i> spp.
Sunflower, common	<i>Helianthus annuus</i> L.
Sweetclover, yellow	<i>Melilotus officinalis</i> (L.) Lam.

Shrubs

Buckthorn, hollyleaf	<i>Rhamnus crocea</i> Nutt.
Cactus, pricklypear	<i>Opuntia</i> spp.
Ceanothus, desert	<i>Ceanothus greggii</i> A. Grey
Cliffrose	<i>Cowania mexicana</i> D. Don
Mountainmahogany	<i>Cercocarpus</i> spp.
Oak, shrub live	<i>Quercus turbinella</i> Greene

Trees

Juniper, alligator	<i>Juniperus deppeana</i> Steud.
Juniper, one-seed	<i>Juniperus monosperma</i> (Engelm.) Sarg.
Juniper, Utah	<i>Juniperus osteosperma</i> (Torr.) Little
Oak, Gambel	<i>Quercus gambelii</i> Nutt.
Pine, ponderosa	<i>Pinus ponderosa</i> Laws.
Pinyon	<i>Pinus edulis</i> Engelm.

Clary, Warren P., Malchus B. Baker, Jr., Paul F. O'Connell, Thomas N. Johnsen, Jr., and Ralph E. Campbell.
1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. USDA For. Serv. Res. Pap. RM-128, 28 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Results from six treated and control watersheds, along with other results from the southwestern pinyon-juniper type, suggest that: (1) mechanical methods of pinyon-juniper removal are not likely to increase water yield; (2) removal of pinyon-juniper overstory by herbicides can increase water yield; (3) there has been no statistical verification of changes in flood peaks or water quality due to treatment; (4) herbage yields increase after virtually all pinyon-juniper treatments, but potential livestock carrying capacity varies greatly due to differences in plant composition; (5) the response by deer to these treatments is, on the average, neutral; (6) the more successful conversion projects just about break even from a benefit-cost standpoint under 1972 economic conditions.

Keywords: *Pinus edulis*, *Juniperus* spp., watersheds.

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PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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